Measurement of the Transverse Single Spin Asymmetry of $p^{\uparrow}+p \rightarrow \eta+X$ at $\sqrt{s} = 200$ GeV

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PHENIX

UC RIVERSIDE UNIVERSITY OF CALIFORNIA

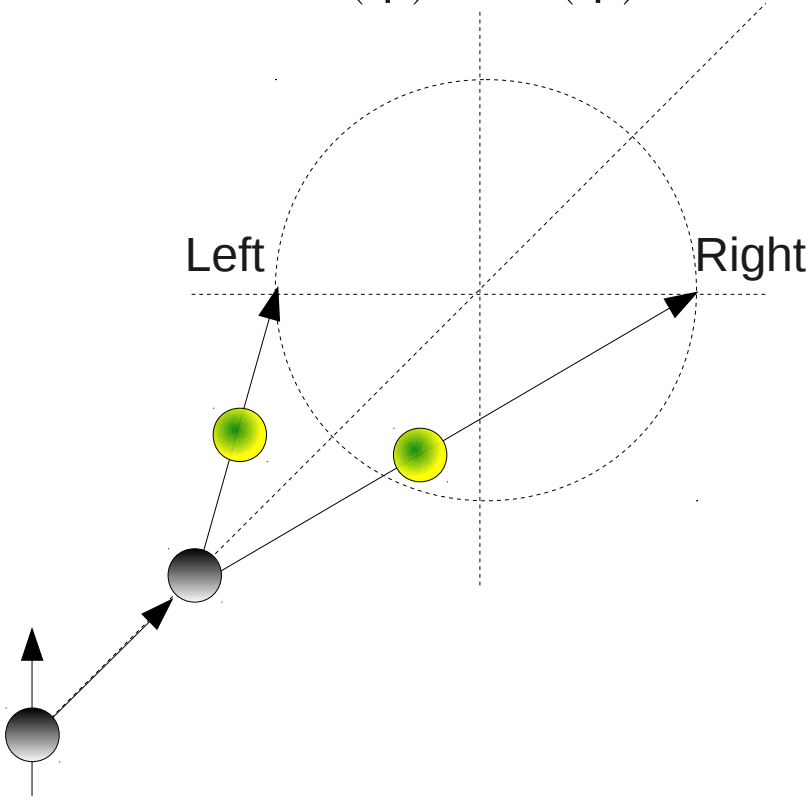
Outline

- Motivation
- Apparatus: RHIC, PHENIX, and the MPC
- η meson reconstruction
- Calculation of A_N
- Results
- Outlook

Definition of A_N for $p^{\uparrow}+p \rightarrow h+X$

A_N: Difference in the **spin-dependent** cross-sections for **particle production**, as a fraction of the **total** cross-section for **particle production**.

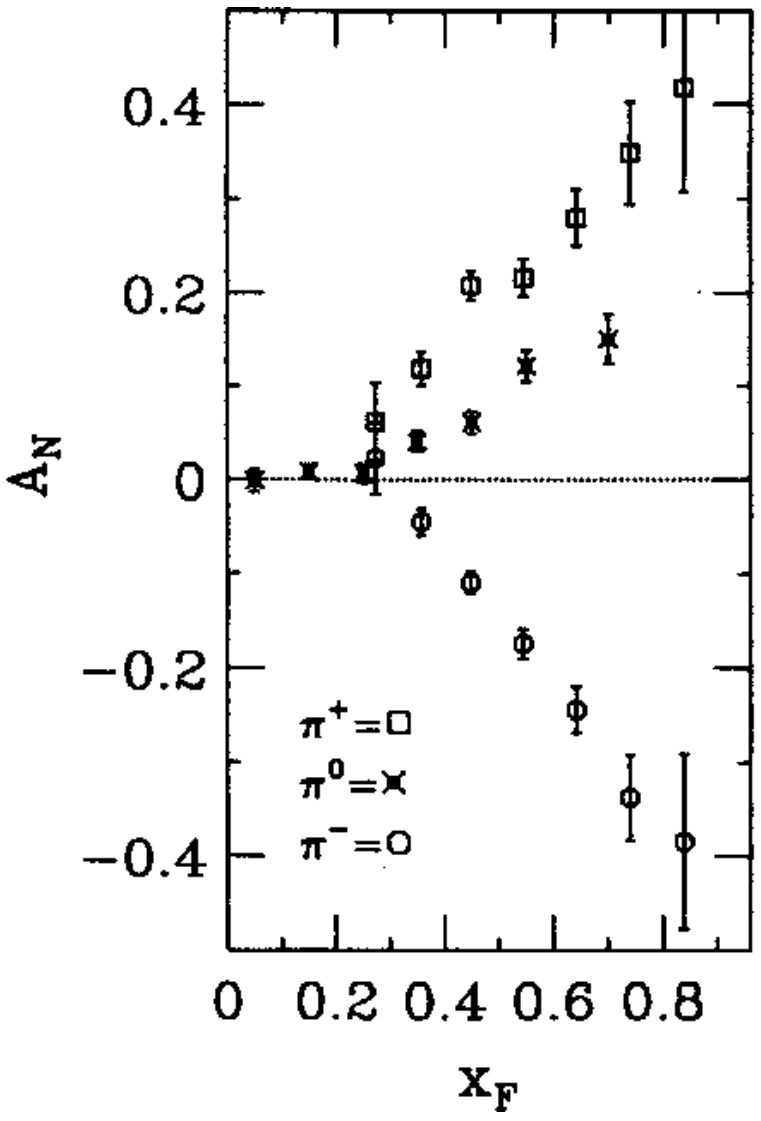
$$A_N \equiv \frac{\sigma^{\uparrow}(\phi)-\sigma^{\downarrow}(\phi)}{\sigma^{\uparrow}(\phi)+\sigma^{\downarrow}(\phi)} = \frac{\Delta\sigma(\phi)}{\sigma(\phi)}$$



- **How do we measure A_N?**
- A_N is a "left-right" asymmetry
- Quantify the difference between hadron production to the left and right of $p^{\uparrow}$ + p collisions.

$$A_N = \frac{1}{P}\frac{N_L^{\uparrow}-N_R^{\uparrow}}{N_L^{\uparrow}+N_R^{\uparrow}}$$

Motivation

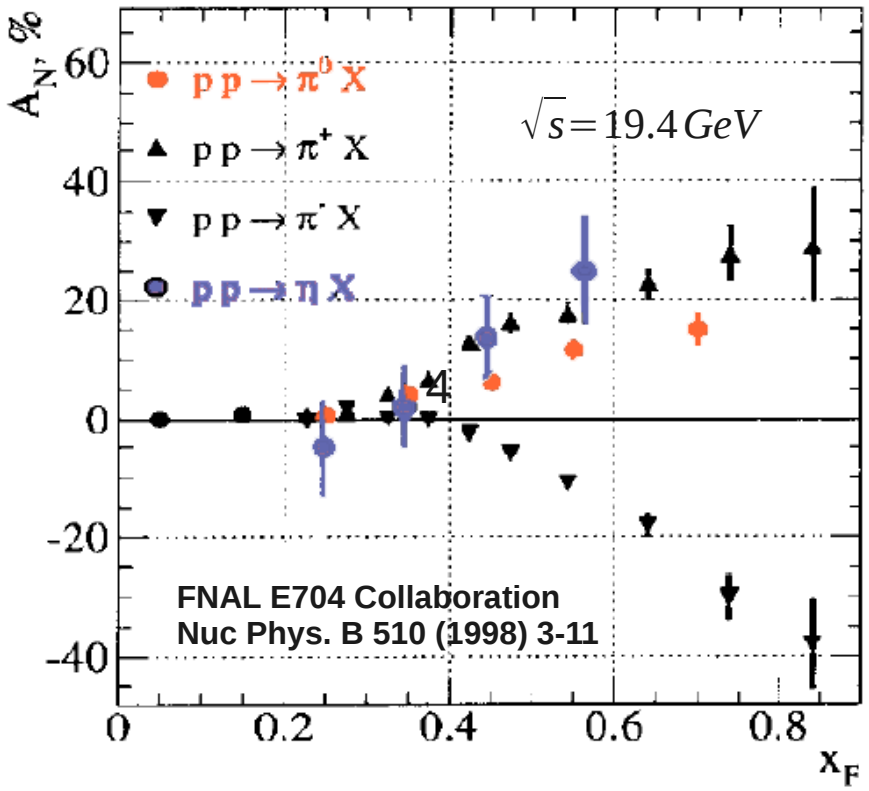


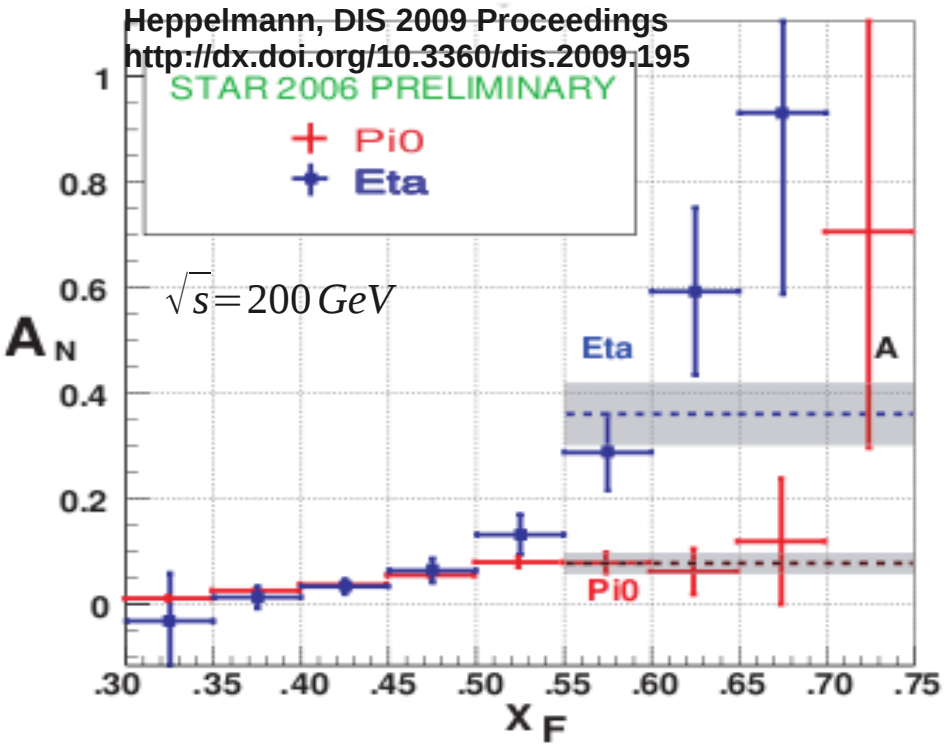
Fermilab E-704 experiment

- **Could be explained by**
  - Collins effect $A_N \propto \delta q(x) \cdot H_1^{\perp}(z, p_{h,T}^2)$
    - Transversity x spin-dep. fragmentation
  - Sivers effect $A_N \propto f_{1T}^{\perp q}(x, k_T^2) \cdot D_q^h(z)$
    - Intrinsic- k_T imbalance
  - Twist-3 effects (Qiu-Sterman, Koike)
  - *Combination of the above*

Motivation

A_N for η meson species measured to be non-zero

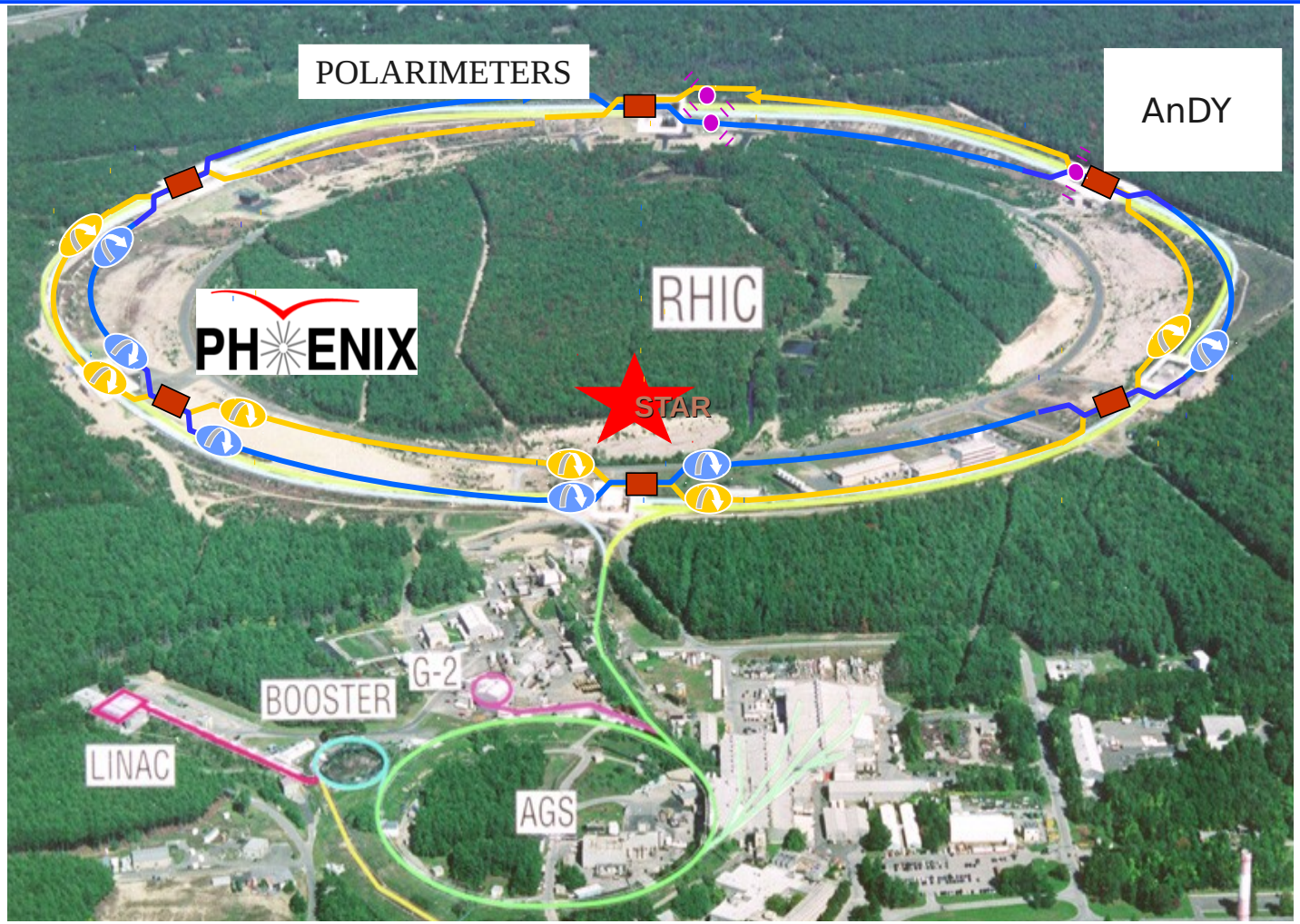




What is η meson A_N at √s = 200 GeV at PHENIX ? Comparable to π^0 A_N or greater?

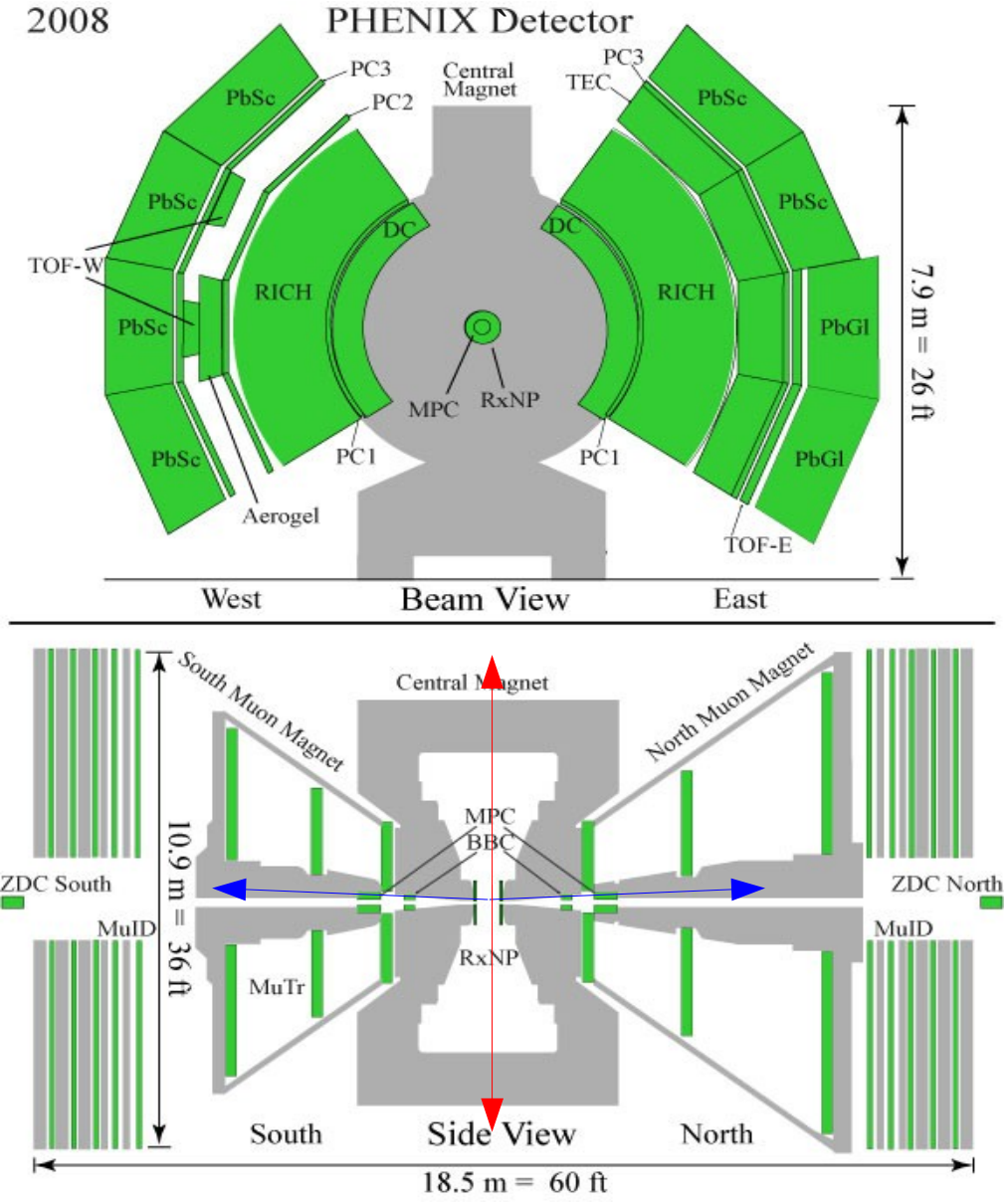
The measurement of η meson A_N will help constrain theoretical models

RHIC at BNL



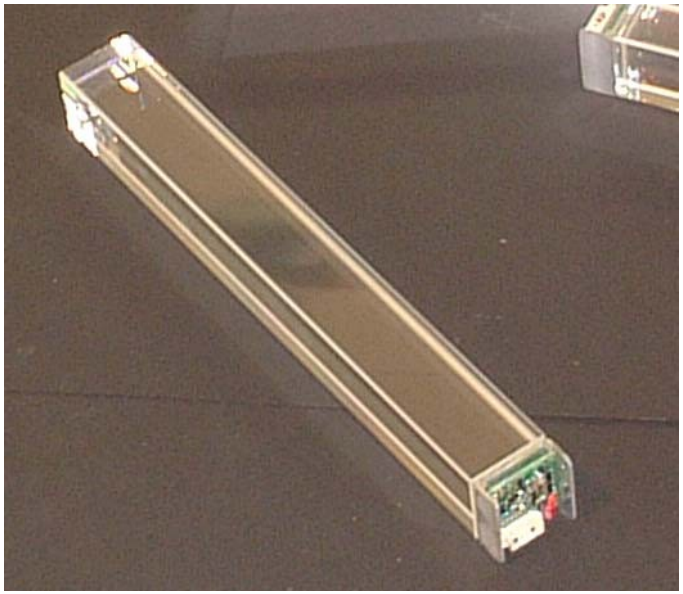
The Relativistic Heavy Ion Collider has provided longitudinally and transversely polarized proton beams at 62, 200, and 500 GeV

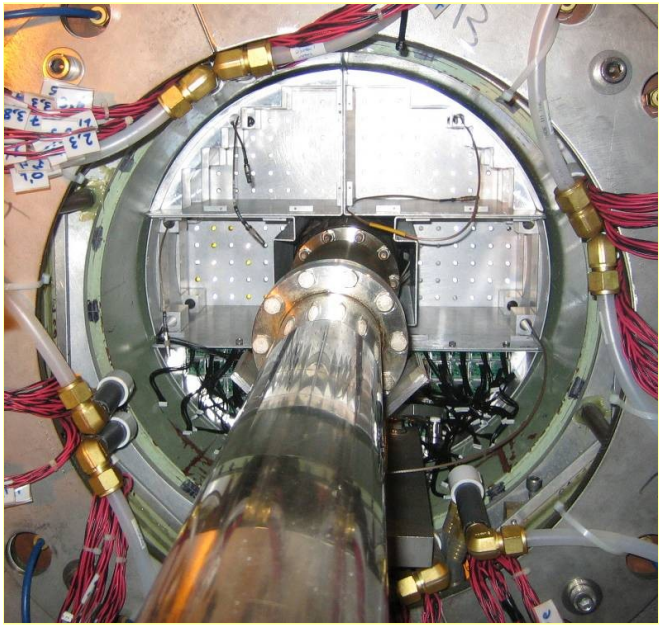
PHENIX Detector



- 2 Central Arms **|η| < 0.35**
  - Identified charged hadrons
  - π^0,**η mesons**, direct photon
  - J/ψ, heavy flavor
- Muon Arms
- 2 MPC Detectors **3.1 < |η| < 3.9**
  - π^0,**η mesons**

MPC detector in PHENIX

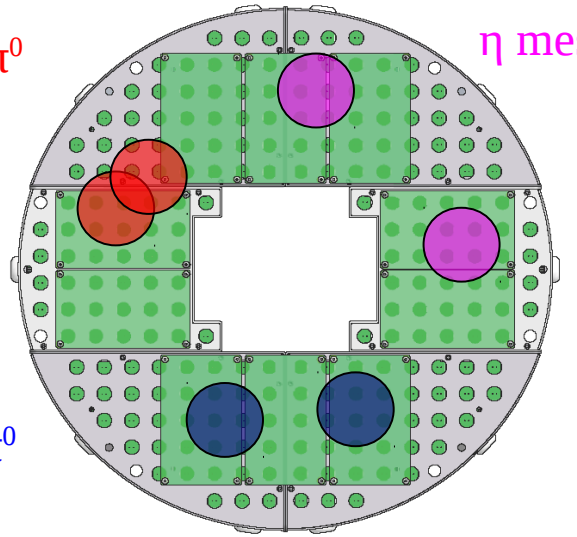




- Electromagnetic Calorimeter
  - 2.2x2.2x18 cm^3 $PbWO_4$ crystal towers
  - 220 cm from nominal interaction point
- ***2 Detectors, North and South***
- Capable of reconstructing
  - η mesons (20 – 70 GeV)
  - Low Energy π^0 (7 - 17 GeV)
  - High Energy π^0 clusters (>17 GeV)

High Energy π^0

η meson



Low Energy π^0

Reconstruction of η mesons

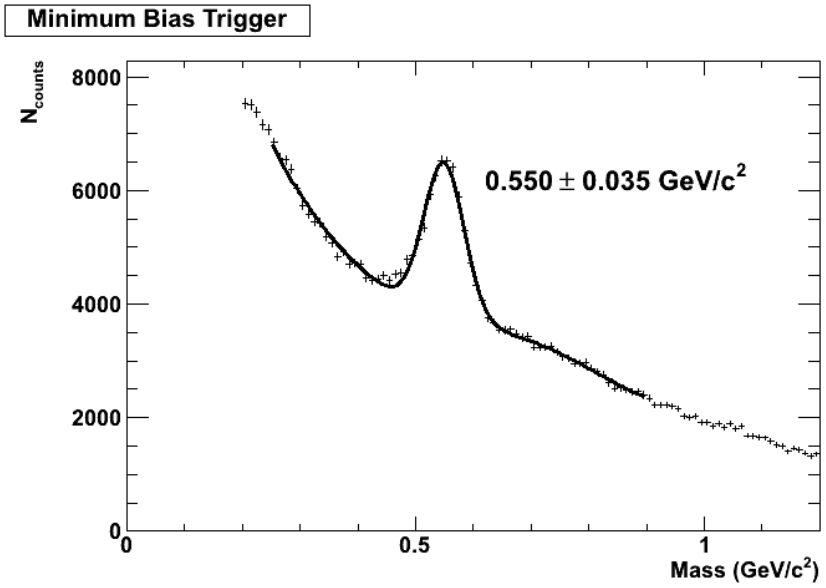
- Data set
  - 2008 Run @ RHIC
  - $\sqrt{s}$ = 200 GeV
  - 5.2 pb^{-1} integrated luminosity
  - 45% average beam polarization
- Triggers
  - Minimum Bias Event Trigger

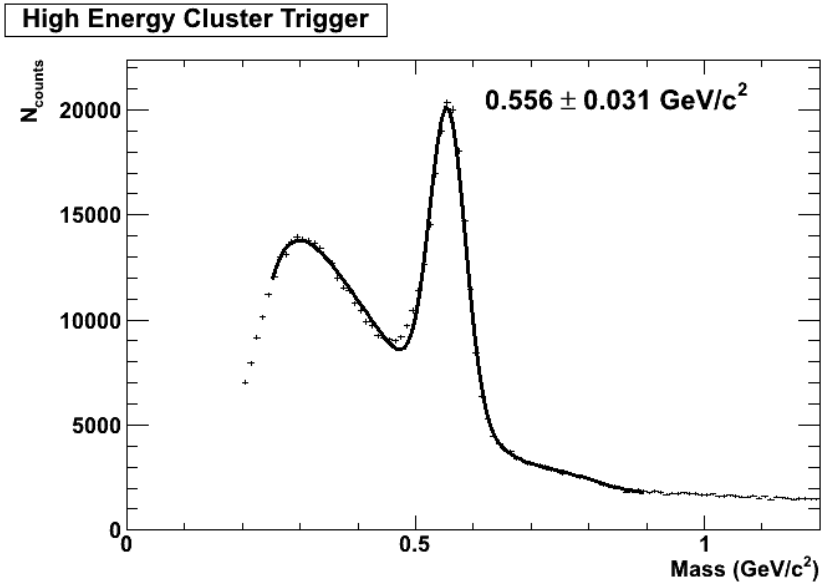
    $0.2 < x_F < 0.4$ ($1.0 < p_T < 2.0$ GeV/c)

    $M_\eta = 0.550 \pm 0.035$ GeV/c^2
  - High Energy Cluster Trigger

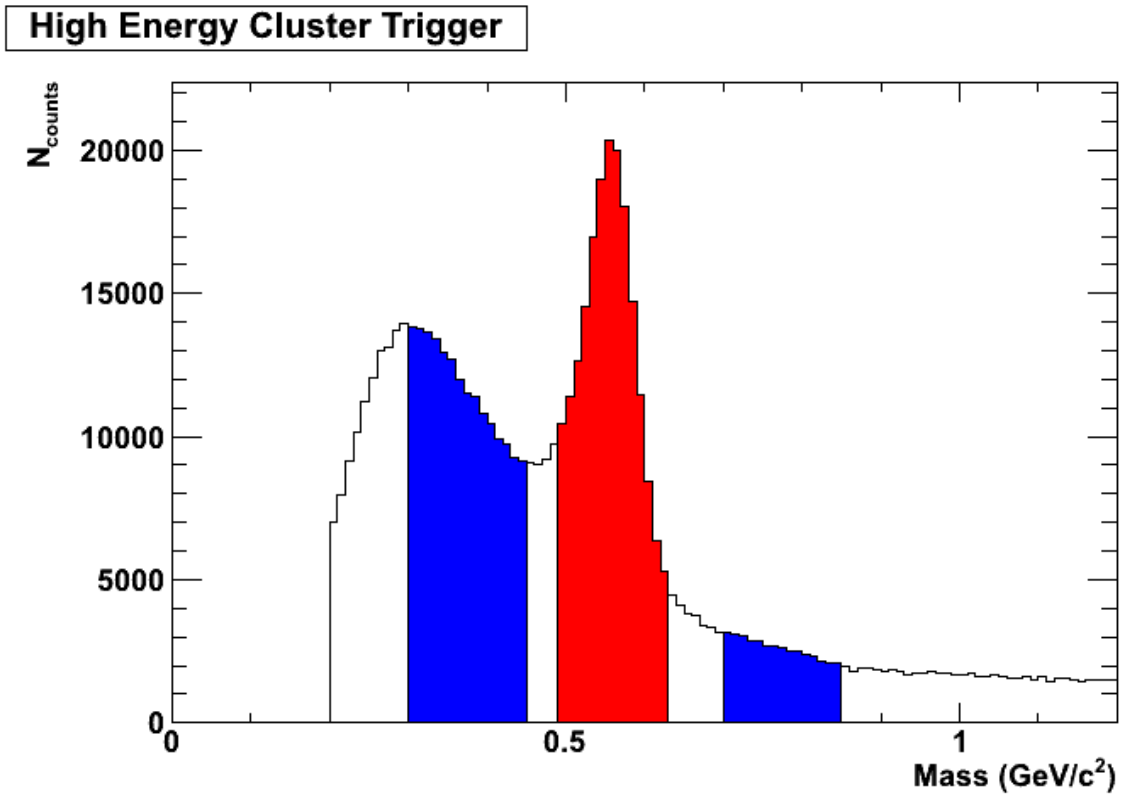
    $0.3 < x_F < 0.7$ ($2.0 < p_T < 4.5$ GeV/c)

    $M_\eta = 0.556 \pm 0.031$ GeV/c^2





Asymmetries



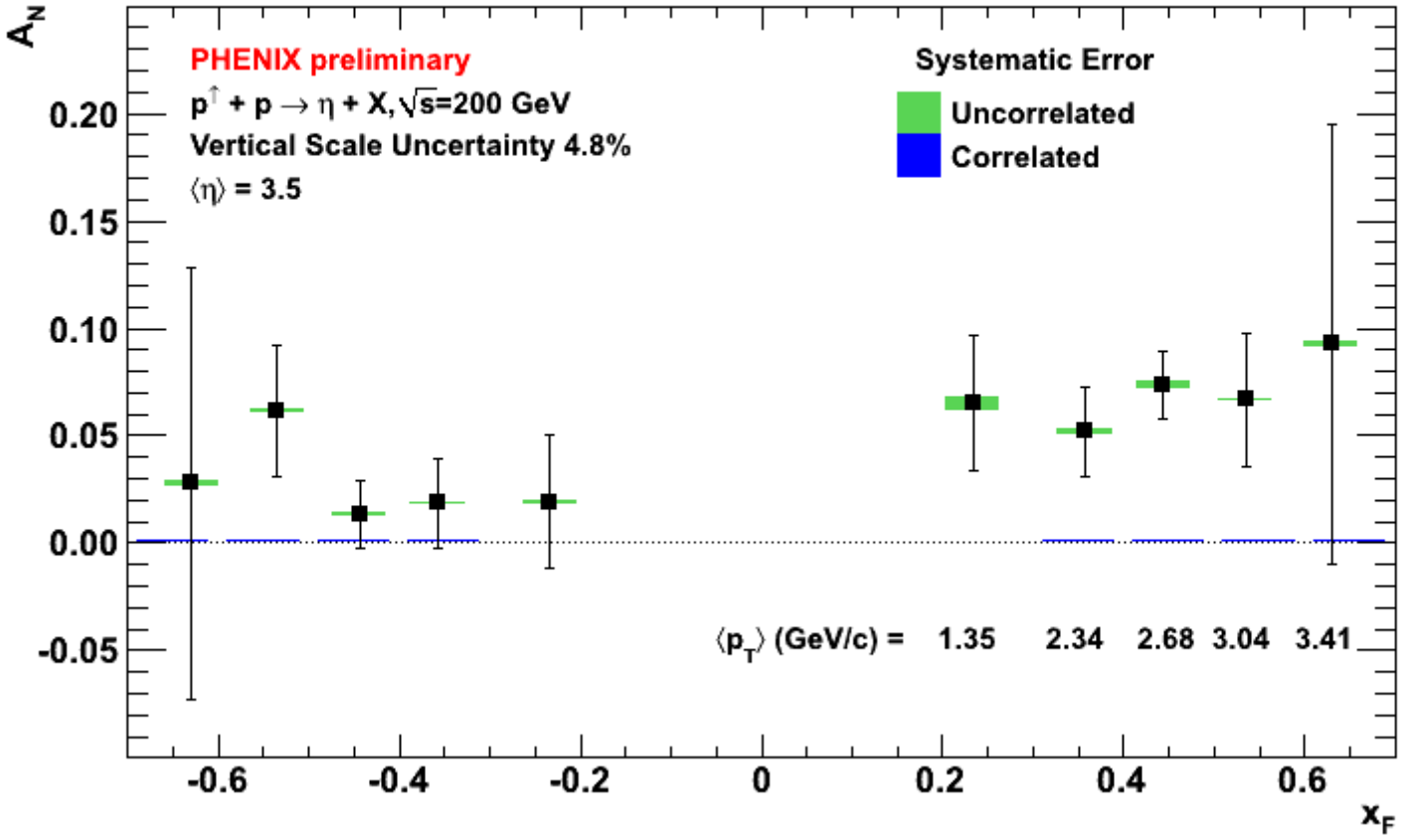
- A_N is calculated in η mass region ($M_\eta \pm 2\sigma$)
- A_N is calculated in low, high mass regions and weighted together
- The background correction formula for A_N is

$$A_N^{\eta} = \frac{A_N^{peak} - r\,A_N^{bg}}{1-r}$$

$0.2 < x_F < 0.3$	$0.3 < x_F < 0.4$	$0.4 < x_F < 0.5$	$0.5 < x_F < 0.6$	$0.6 < x_F < 0.7$
0.69	0.45	0.35	0.35	0.34

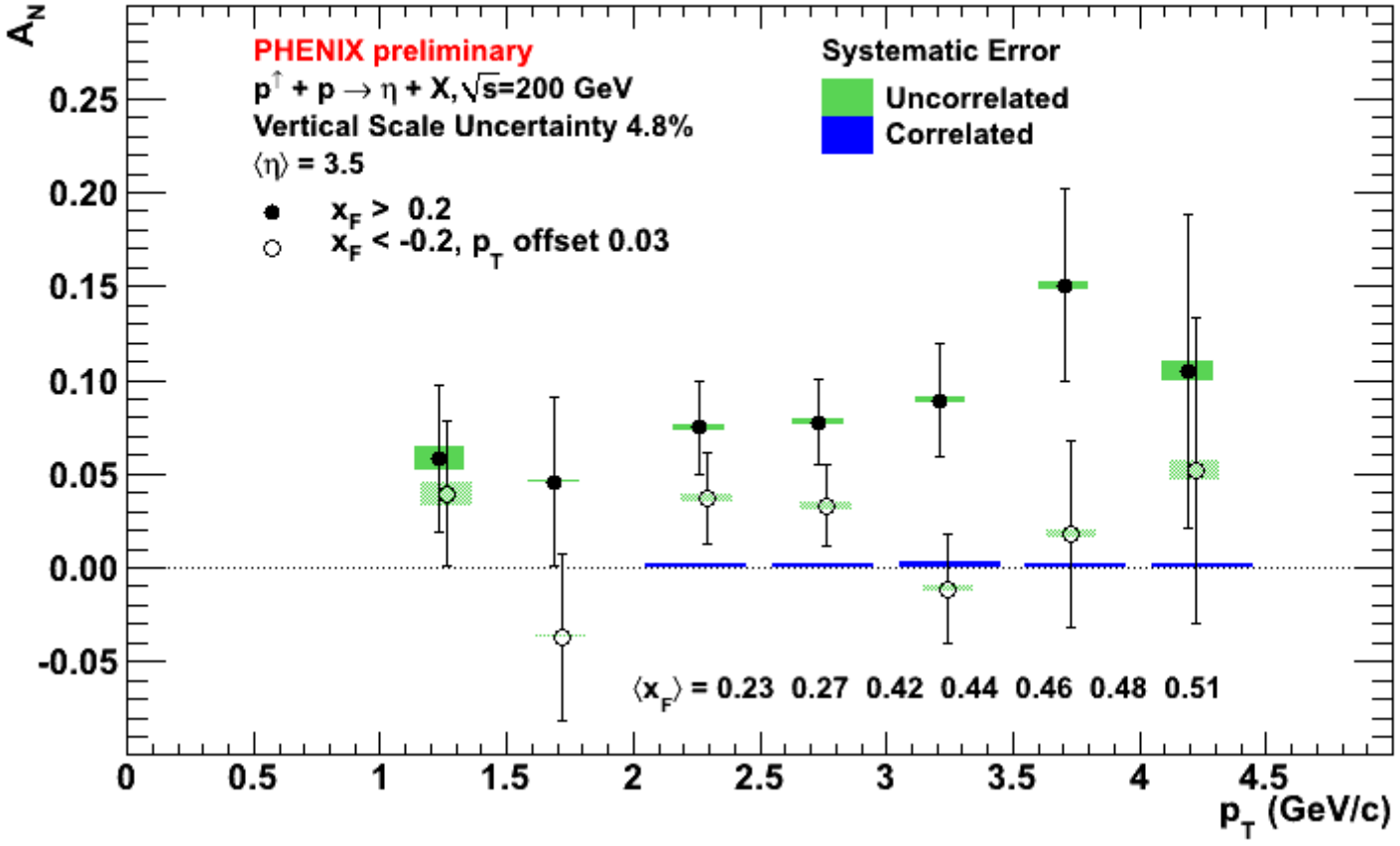
$$r = \frac{B}{S+B}$$

x_F dependence of η meson A_N



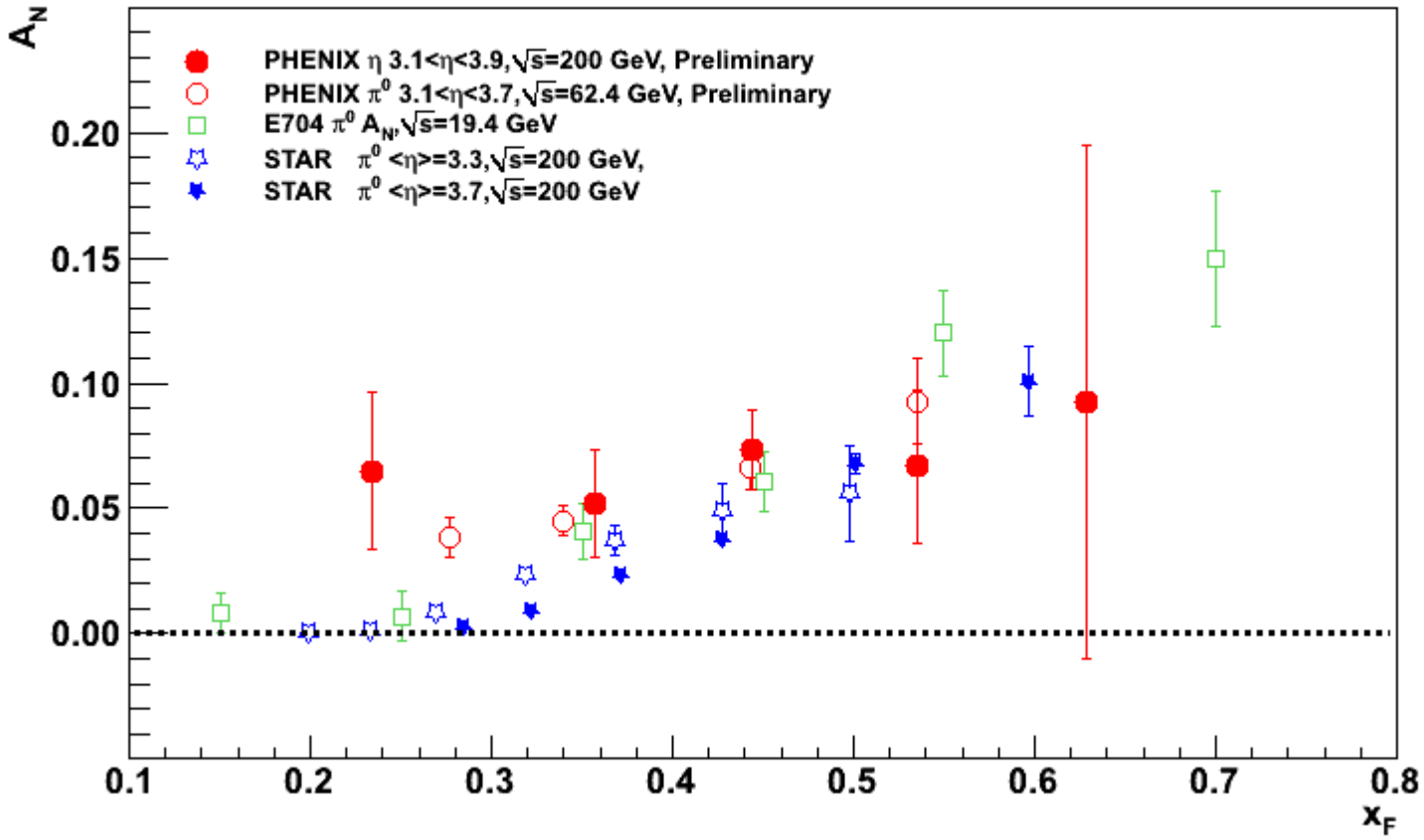
- There is a 5 to 10 percent positive A_N at positive x_F
- Weighted mean of negative x_F values is 0.022 ± 0.011

p_T dependence of η meson A_N



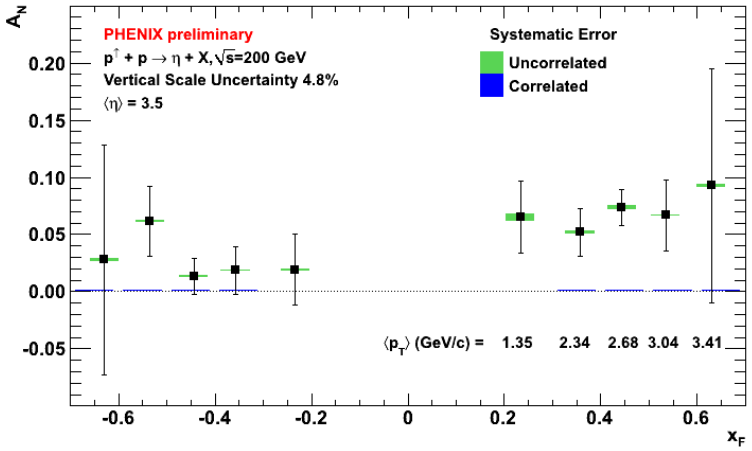
- Positive p_T dependent A_N for $x_F > 0.2$
- No clear sign of high p_T decrease

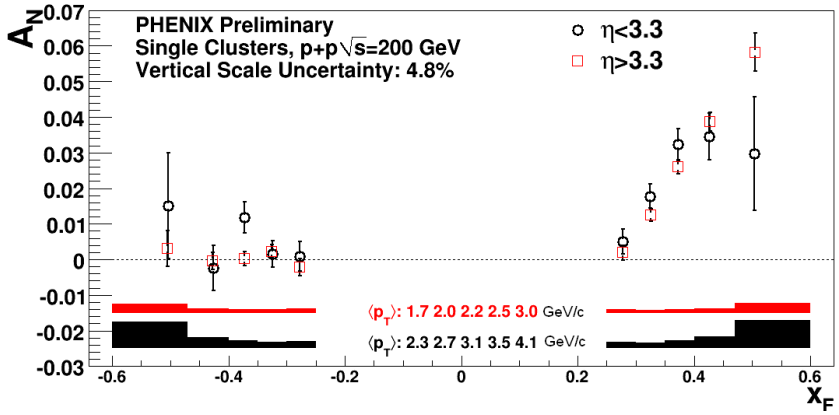
Comparison to other Forward π^0 A_N results

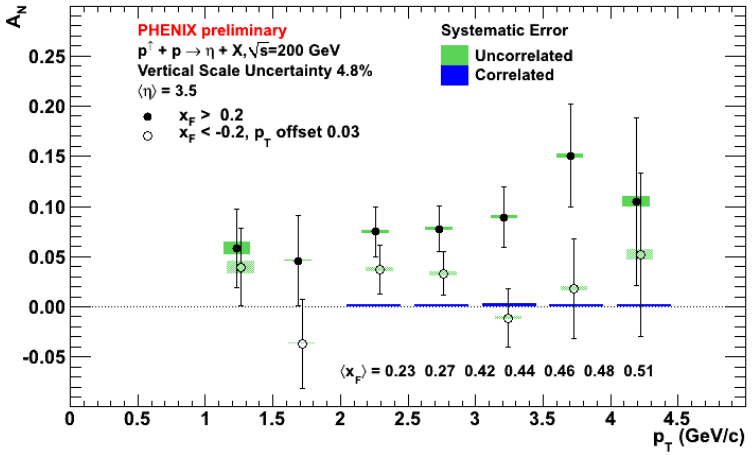


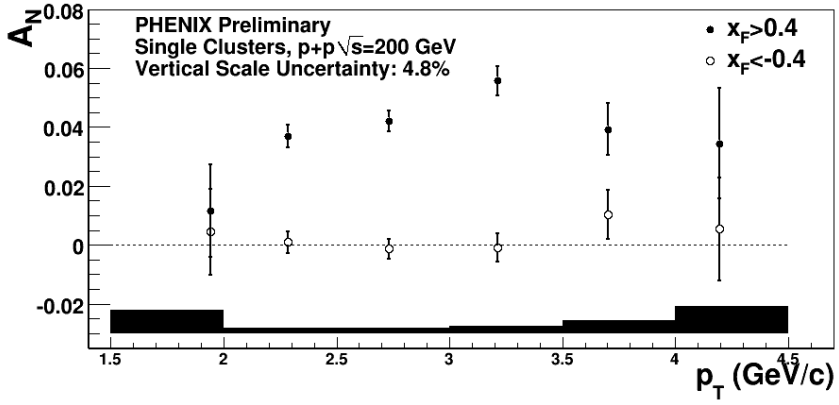
- η meson A_N compared to several π^0 meson A_N

Comparison to MPC Cluster A_N



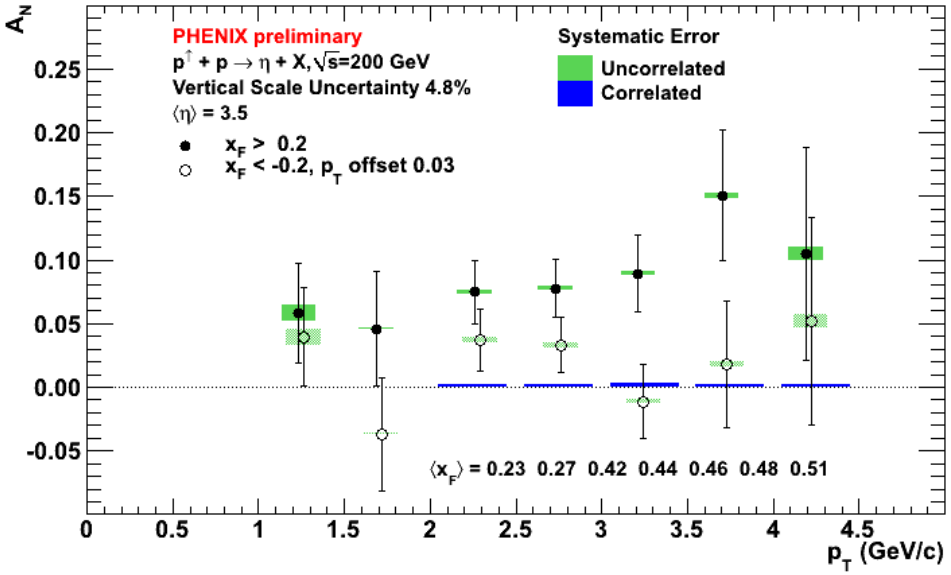


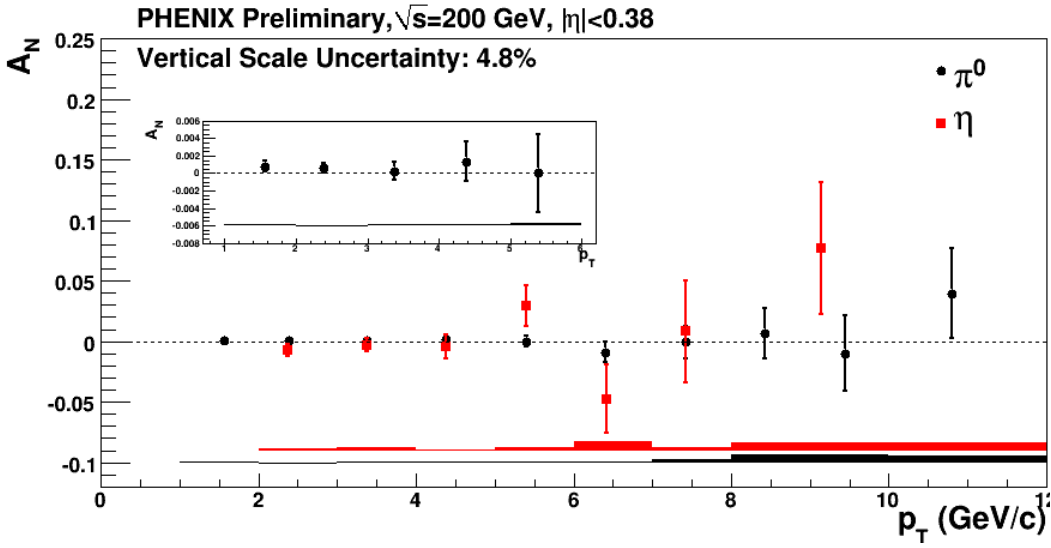




- Same Data Set (RHIC 2008 run)
- Cluster A_N expected to be ~90% merged π^0 clusters

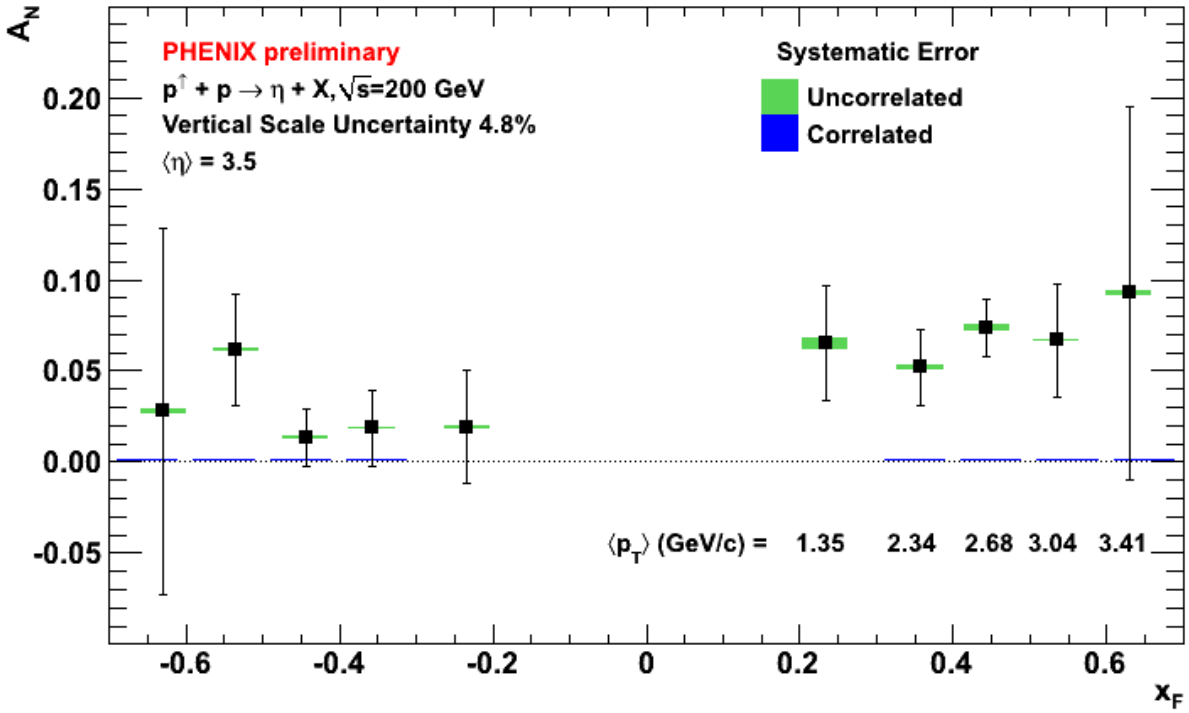
Comparison to PHENIX Central Arm A_N



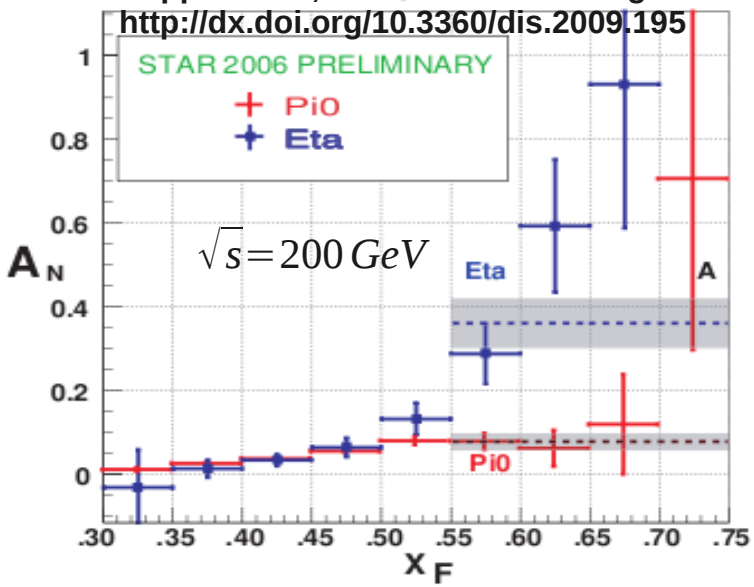


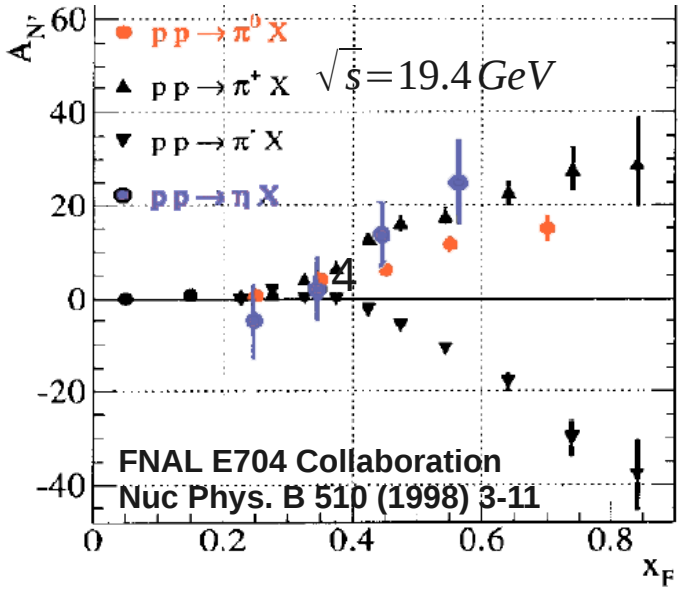
- Central Rapidity consistent with zero
- Forward Rapidity positive ($x_F > 0.2$)

Comparison to other Forward η meson A_N results



Heppelmann, DIS 2009 Proceedings
http://dx.doi.org/10.3360/dis.2009.195



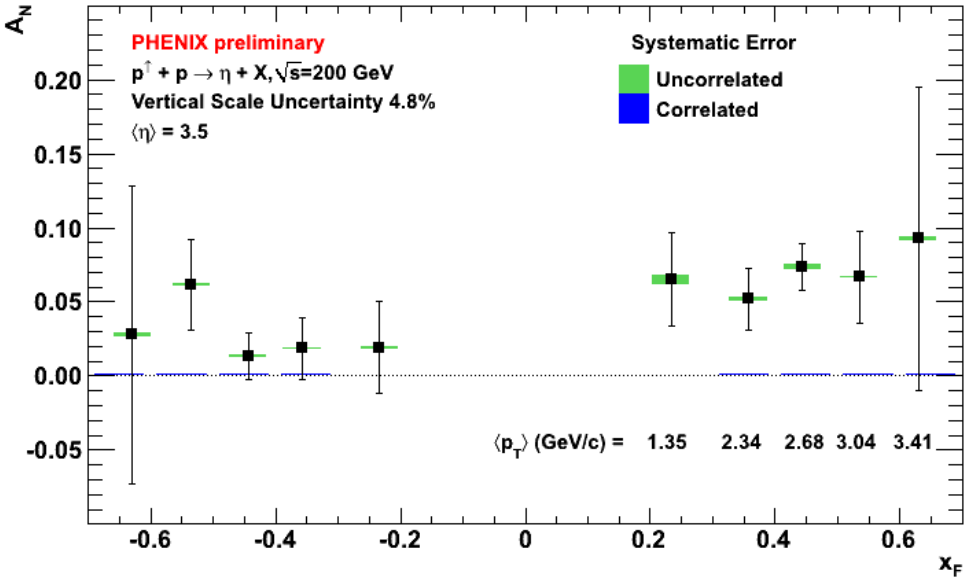


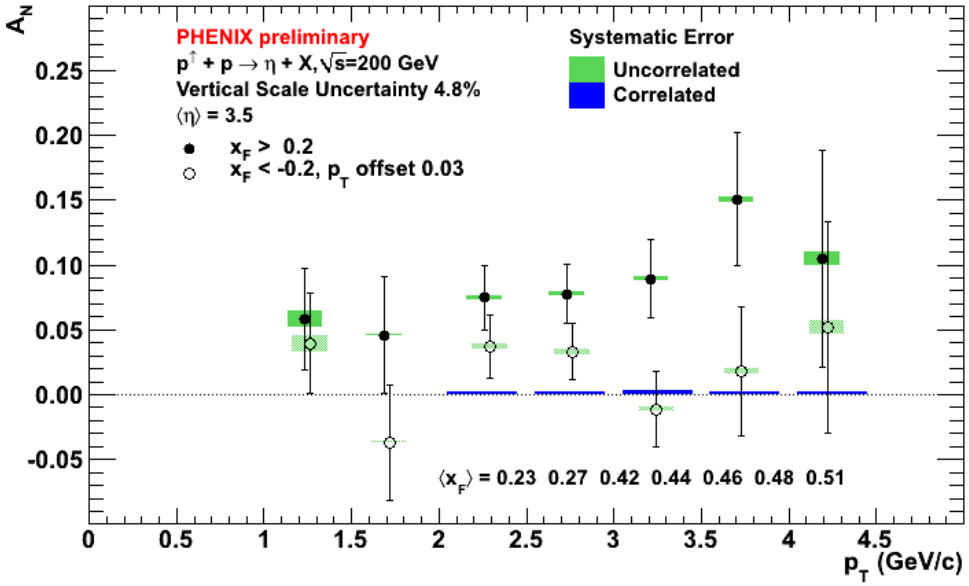
The measurement of η meson A_N comparison

No sharp rise above 0.55 x_F as seen by STAR

Conclusions & Outlook

- Conclusions
  - η meson x_F dependence of A_N results similar to previous π^0 results.
  - η meson p_T dependence of A_N results show clear positive asymmetry to 4.5 GeV/c
- Outlook
  - Detailed simulation study of background
  - The cross section will be calculated

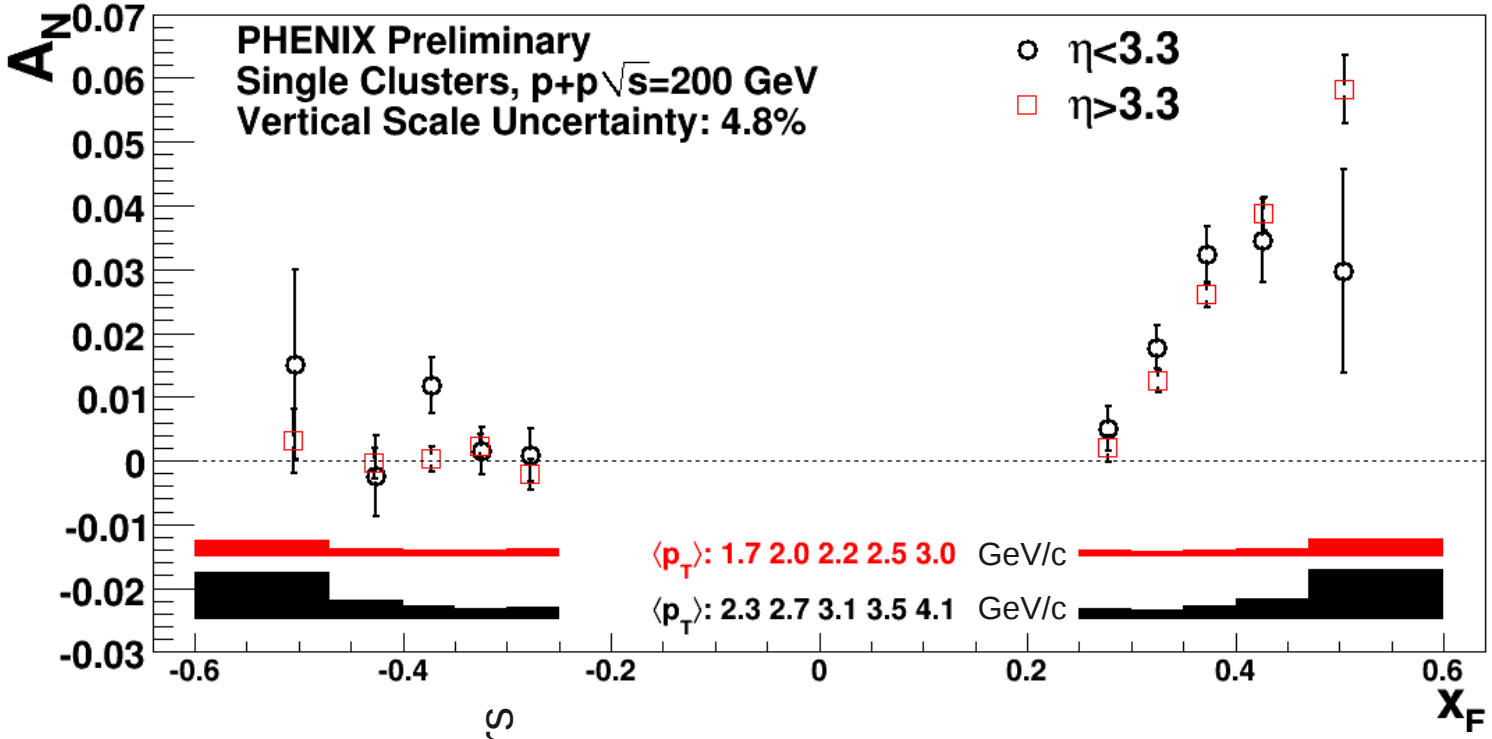

PHENIX preliminary
$p^{\uparrow} + p \rightarrow \eta + X, \sqrt{s}$=200 GeV
Vertical Scale Uncertainty 4.8%
$\langle\eta\rangle$ = 3.5
Systematic Error
Uncorrelated
Correlated
$\langle p_T \rangle$ (GeV/c) = 1.35 2.34 2.68 3.04 3.41
A_N
x_F

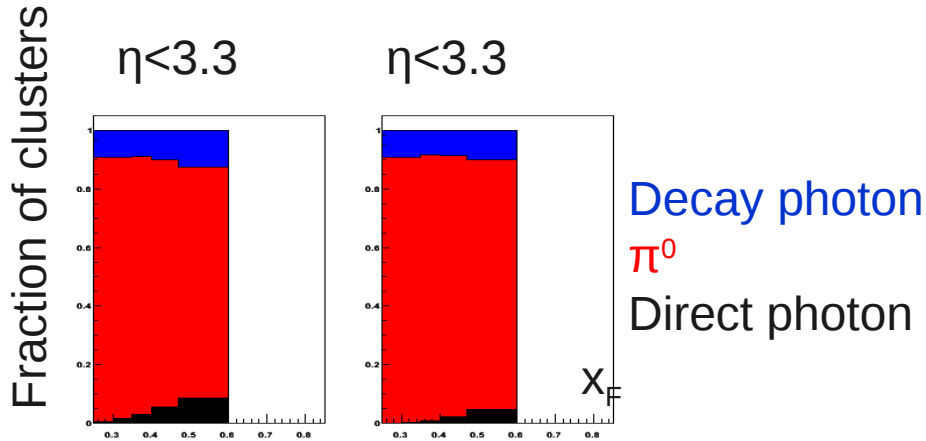

PHENIX preliminary
$p^{\uparrow} + p \rightarrow \eta + X, \sqrt{s}$=200 GeV
Vertical Scale Uncertainty 4.8%
$\langle\eta\rangle$ = 3.5
$x_F > 0.2$
$x_F < -0.2$, p_T offset 0.03
Systematic Error
Uncorrelated
Correlated
$\langle x_F \rangle$ = 0.23 0.27 0.42 0.44 0.46 0.48 0.51
A_N
p_T (GeV/c)

Thank you!

Backup

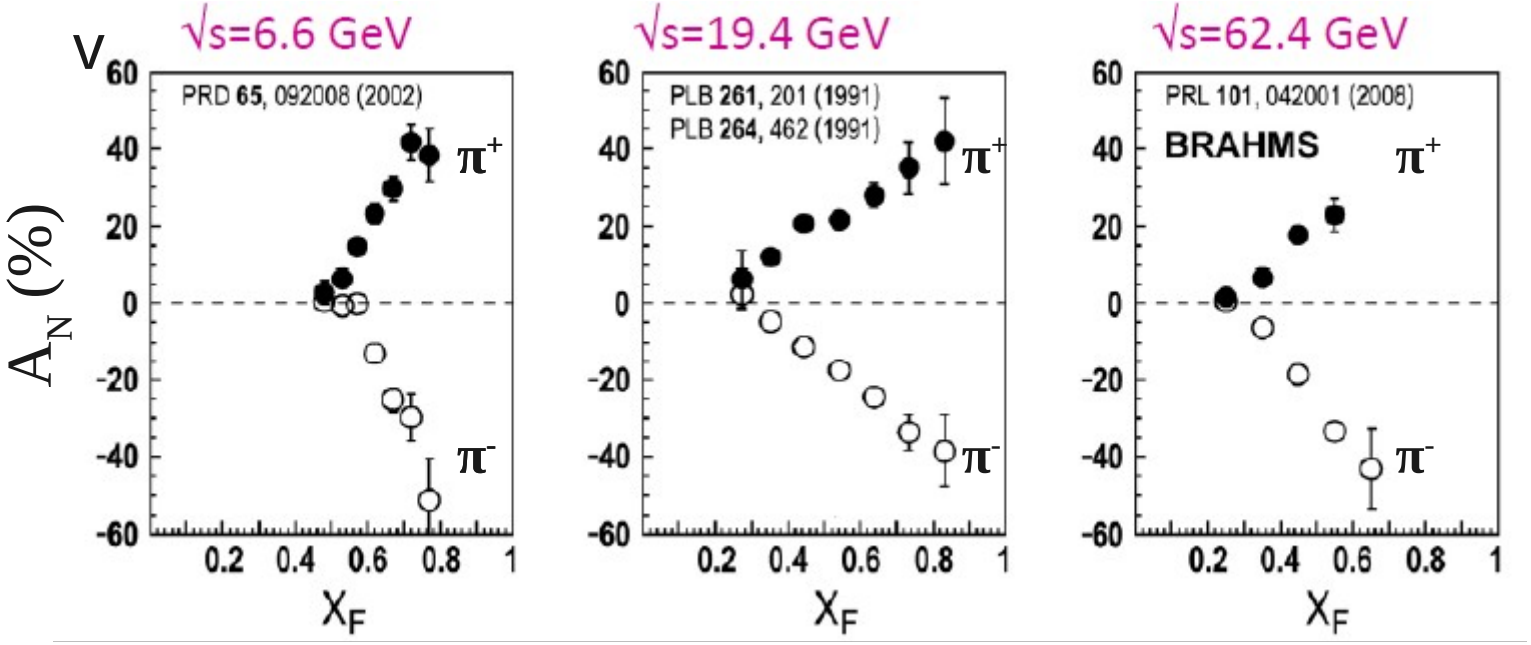
Forward Single Cluster A_N x_F, binning





Motivation

A_N measured at various collision energies to be non-zero



$$x_F = \frac{2p_l}{\sqrt{s}}$$

i.e. fraction of proton energy given to forward momentum of hadron

Collinear pQCD at leading twist interaction has small spin dependence, i.e. no asymmetry

Can initial or final state effects produce a nonzero asymmetry?

Origin of A_N from $p + p^{\uparrow} \rightarrow h + X$

Proton Structure **pQCD**

$$\frac{d^3\sigma(pp \rightarrow hX)}{dx_1\,dx_2\,dz} \propto q_1(x_1)\cdot q_2(x_2) \times \frac{d^3\hat{\sigma}^{\uparrow}(q_i q_j \rightarrow q_k q_l)}{dx_1\,dx_2} \times FF_{q_k q_l}(z, p_{h,T})$$

Hard scattering

fragmentation function

- "Transversity" quark-distributions and Collins fragmentation
  - Correlation between proton-spin and quark-spin and spin dependent fragmentation

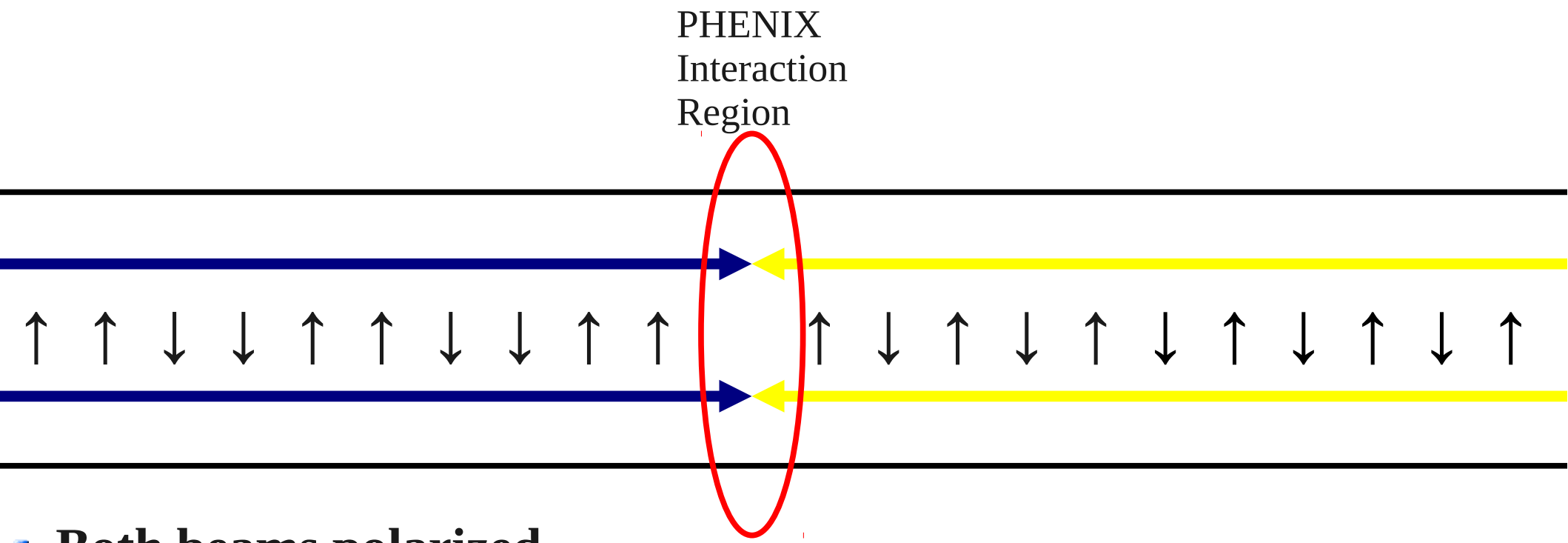
$$A_N \propto \delta q(x) \cdot H_1^{\perp}(z, p_{h,T}^2)$$

- Sivers quark distribution
  - Correlation between proton spin and transverse quark momentum

$$A_N \propto f_{1T}^{\perp q}(x, k_T^2) \cdot D_q^h(z)$$

- Higher Twist Effects

Polarized Beams



- **Both beams polarized**
- Variation of bunch polarization direction minimizes systematic uncertainties in measurement
- For transversely polarized beams, allows for two independent A_N measurements